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Laboratorium voor Oecologie der Dieren, Zoogeografie en Natuurbehoud,
Rijksuniversiteit Gent, België

Population dynamics of *Orchesella cincta* (Collembola) in experimental conditions

JOHAN MERTENS and JEAN-PIERRE BLANCQUAERT

With 6 figures

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1. Introduction

An understanding of the autecology of *Orchesella cincta* is important for a synecological insight of terrestrial ecosystems to which Collembola contribute considerably.

The population dynamics of *Orchesella cincta* remains unclear, because only the reproductive cycle is incompletely described in earlier works.

This paper reports on the reproduction and development of *O. cincta* under well-defined laboratory conditions. Survivorship curves and growth curves are described.

2. Materials and methods

The organisms were collected in the botanic garden of the University of Ghent.

Laboratory cultures were set up and maintained using the method of GOTO (1960), however without adding any fungicides. All cultures were kept in permanent darkness at a temperature of 20 °C (± 1 °C) and at a relative humidity of 98–100 %. Dried yeast *(Torula utilis)* was provided as food.

Single organisms could be studied by keeping them in individual culture jars under similar conditions as the stock cultures. These culture jars are glass-tubes (1.4 ⌀, ± 4 cm height) the bottom of which consisted of a plaster-charcoal (9/1 v/v) substrate. The tubes were closed with a plastic membrane. Those recipients were stocked in a collector on a bottom of water saturated filter paper.

Each animal is checked daily for life or death, the appearance of an exuvium, of spermatophores or of eggs.

Total of 273 animals, of which 49 were males, were observed this way. The demographic aspects were evaluated in a dynamic life-table, the isolated organisms being the members of the population (KREBS 1972).

To describe growth curves, the body length of the individual animals was measured daily using a stereoscopic microscope at a magnification of 25×.

The method was reliable at a 0.01 mm interval. The lowest variation and the highest confidence was obtained by defining the body length as the distance between the front of the second thoracic segment and the end of the fifth abdominal segment in dorsal view. All data corresponded to this standard length. 32 ± 4.4 % of the total body length took no part in the standard length.

To study the influence of temperature on the embryonic development, eggs younger than 12 hours were brought at the experimental temperature and were controlled daily. The time of the chorion-split, the appearance of eye-pigmentation and the moment of hatching were noted. Experiments were performed at 0 °C (158 eggs), at 10 °C (178 eggs), at 20 °C (82 eggs) and at 30 °C (130 eggs).

3. Results and discussion

3.1. Postembryonic development

3.1.1. The survivorship and life expectancy

The survivorship (L_x) and life expectancy (e_x), with one day as unit of time, are shown in Fig. 1 and Fig. 2 resp. From these curves it can be concluded that:

(1) The maximal lifetime of *O. cincta* females and males is about 270 days and 200 days respectively.

(2) 50 % of the organisms die before the age of 36 days.

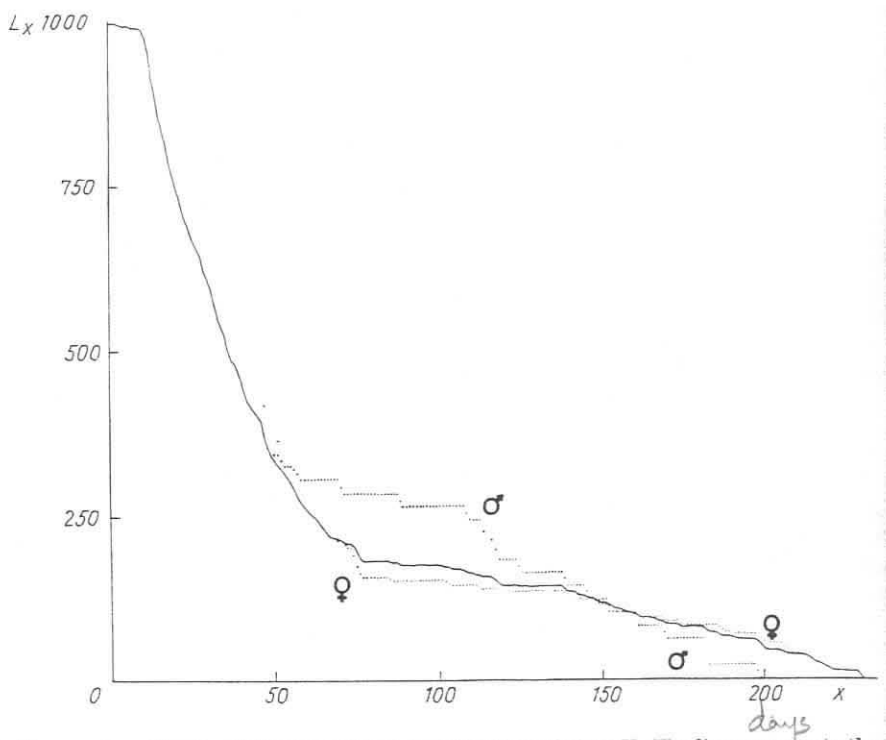

Fig. 1. The survivorship L_x of the population as a function of time X. The line represents the whole population, the dots correspond to the males (♂) or the females (♀).

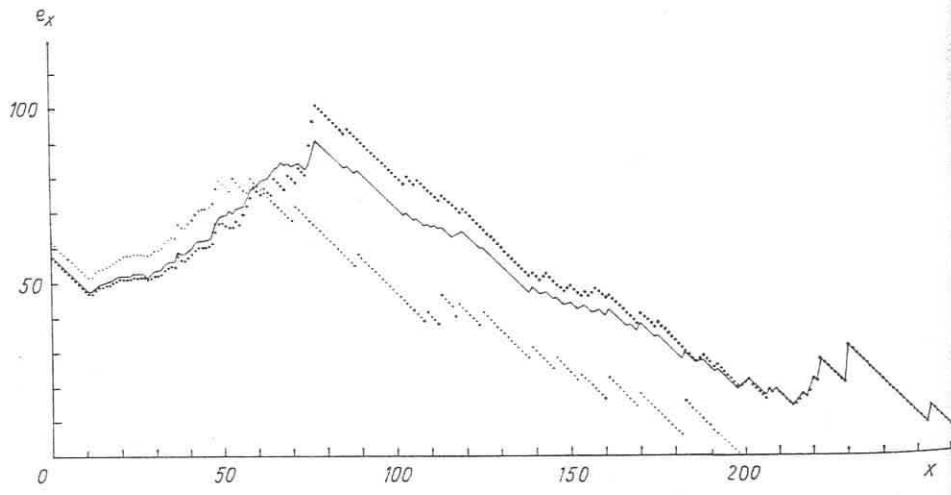

Fig. 2. The life expectancy e_x of the animals as a function of the life time (one day as unit of time). e_x values of the females, the males and both sexes are represented by small dots, hard dots and a line respectively.

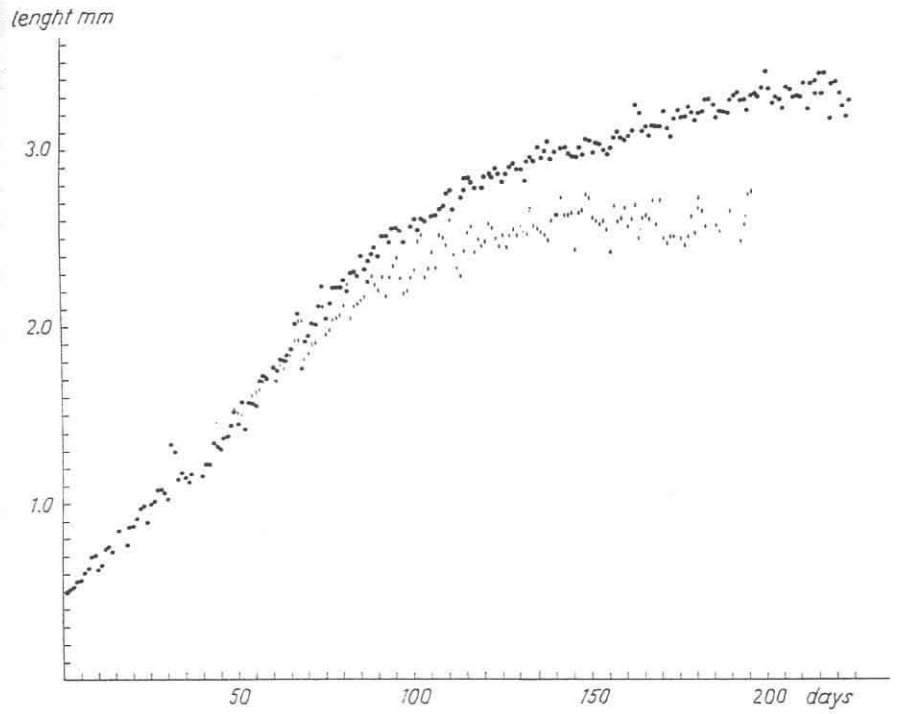

Fig. 3. The growth curve of the females (●) and the males (▮).

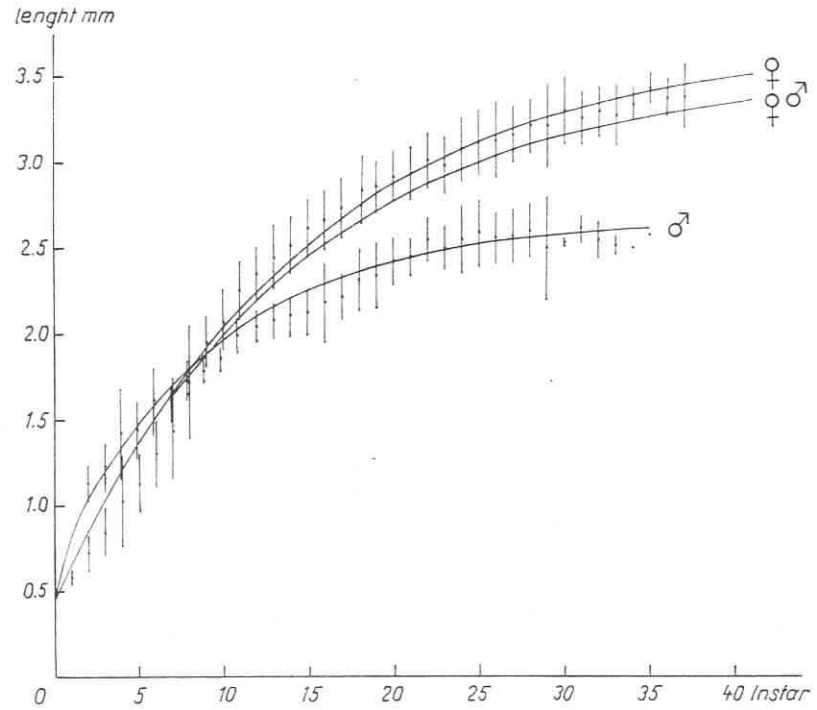

Fig. 4. Correlation between the body length and the age-class (instar).

(3) During the first 10 days of life there is a slight mortality (> 1 %). The mortality increases at the first ecdysis.

(4) The high and constant mortality coefficient extends over a life-time of about 75 days in the females and of about 50 days in the males (this results in an increase of e_x, because at each short time interval d_x, in which an organism survives, its chance of survival de_x increases).

(5) After this period the life expectancy slowly decreases in the females with increasing age. The mortality coefficient is low and almost constant, until the total population has disappeared. In the males the same phenomenon occurs in a shorter time interval, about 60 days (50 till 110), after which the mortality increases (110 till 200). The male population becomes extinct after 200 days.

(6) From 1. and 5. it follows that all springtails of a population, belonging to the life class between 200 and 270 days are females.

(7) Thus a sex correlated difference in the survivorship curves can be concluded.

3.1.2. The growth curve

Orchesella grows during its whole lifetime. As is shown in fig. 3 the body length of both sexes increases almost linear to the 100th day. Thereafter growth slowed down and strives towards a limit. From the 50th day onwards males grow less fast than females. It is clear from fig. 4 that there is a relationship between body length and instar or age class. A mathematical model for this relationship is found by convergence of coefficients and parameters of a polynomial. A minimal deviation is found for the function $f_i = (F - f_0)\, e^{-ki}$ in which i is the age class (coordinate of the abscissa, f_i the body length (coordinate of the ordinate), F the limit for a very high i (maximal length), f_0 the minimal length, corresponding to $i = 0$, and k the exponent by which the length increases with the age class. By curve fitting a value of 0.066 for k is found. The coefficients are $F = 3.732$ mm and $f_0 = 0.449$ mm. The sum of the squares of the deviation is 27.060. This corresponds with an average deviation of 0.209 mm per measurement. The maximal length of the females (3.732 mm) is significantly greater than the maximal length of the males (2.669 mm). Development of the females ($k = 0.066$) is slower than of the males ($k = 0.105$).

On the contrary, the growth period in females is scattered over more instars than in males. The growth curve of the total experimental population (males and females) follows nearly the curve of the females because, there are significantly less males in the population, and the mortality starts earlier in males than in females, so that the proportional overweight of the females in the population increases with time. The characteristics of the curve are: $F = 3.529$ mm, $f_0 = 0.449$ mm, $k = 0.0698$. The sum of the squares of the deviation is 57.644 or an average of 0.274 mm.

3.1.3. Reproductive cycle and reproduction

3.1.3.0. Preliminary note

According to Handschin & Lindenmann (1948), Lindenmann (1950) and Handschin (1953) *Orchesella* becomes sexually mature between the 10th and 13th instar. Since the existence of spermatophores is known since 1952 (Schaller), these data correspond to the maturity of females. Poggendorf (1956) records the 8th till 12th instar as the maturity stage of *Orchesella* males. Korr (1968) finds the 7th and 8th instar, going on the 11th to 12th instar as the minimal lifetime of reproduction in *O. villosa*.

Our observations bear out the data of Poggendorf & Korr, except one in which spermatophores were produced after the fifth ecdysis.

3.1.3.1. The males

Poggendorf (1956) and Mayer (1957) found an alternation of reproductive and non-reproductive instars. The sexually active period outlasts the sexually non-active period. In *O. cincta* an active period of 3—4 days (25 °C) and 5.5 ± 1.7 days (20 °C) and an in-

active period of 2—3 days (25 °C) and 3.4 ± 1.1 days (20 °C) are described (POGGENDORF 1956; JOOSSE, BURGMAN & VELD 1973). MAYER (1957) and KORR (1968) describe an active period of 6—7 days and an inactive period of 3—5 days at "room temperature" in *O. villosa*. We found an active period of 6.7 ± 3.2 days (max. 14 days, min. 3 days, n = 71) at 20° ± 1 °C. The difference between the two periods was significant ($p < 0.001$).

The production of spermatophores is highest during the first days of a sexually active period (40—60 spermatophores deposited per day) and decreases gradually to zero towards the end of the period. During the whole active period an average of 20 spermatophores are deposited a day. With an active period, lasting 6.7 ± 3.2 days from 70 to 198 spermatophores could be deposited.

SCHALLER (1953) reports a production of about 300 spermatophores in a sexually active period. MAYER (1957) reports an average production of 30 spermatophores in an active period. We doubt these numbers, because the observed spermatophores do not necessarily correspond to the number of actually deposited spermatophores. If a male touches a spermatophore, older than 8 to 10 hours, he eats it (SCHALLER 1953), but most of the time he immediately replaces it by a new one at the same place. This replacement-behaviour is very pronounced at the start of an active period and decreases or disappears completely towards the end of it. Moreover the individual differences in the production of spermatophores and the differences between successive active periods are so variable that mean values are to be considered with some restrictions. We find a decrease of spermatophore production with increasing age as described by JOOSSE, BURGMAN & VELD (1973).

3.1.3.2. The females

Also in females we found alternating reproductive and non-reproductive instars. At 20° ± 1 °C the active period lasted 5.47 ± 2.41 days (max. 12, min. 2, n = 72) and the inactive period lasted 6.11 ± 2.71 days (max. 14, min. 2, n = 75), the difference between the periods was not significant ($p > 0.1$).

JOOSSE, BURGMAN & VELD (1973) found alternating long (6.0 days) and short (5.6 days) instars in three isolated females at 20 °C although no oviposition occurred.

As SCHALLER (1953, 1970) — MAYER (1957) and CHOUDHURI (1963) we observe most females reproducing 3 to 6 times. Roughly the longevity of a female extends over 30 instars.

Being adult from the 8th to 10th instar onwards, the mature period consists of about 20 instars, half of it being sexually active periods (10). So each female can reproduce 10 times, a fact that never occurred in our experiments.

The reproduction starts the first day of the active period and ends after a few days. We found a mean time of reproduction per active instar of 2.64 ± 1.56 days (n = 12) while JOOSSE, BURGMAN & VELD (1973) found 1.4 days. The average reproductive time (2.67 days) per average active period (5.47 days) is 0.49, which is in good agreement with the value of 0.5 given by JOOSSE, BURGMAN & VELD (1973). The number of eggs is very variable. We found an average of 29 ± 24 (max. 63, min. 1) eggs per female per active instar. Values of 31.1 ± 19.4, 56.7 ± 27.5, 60.8 ± 9.6 and 67.0 ± 12.8 (JOOSSE, BURGMAN & VELD 1973) of 8 to 12 (HANDSCHIN 1950) and of 57.5 (MAYER 1957) are reported.

Otherwise MAYER (1957) reports 50 eggs only as the average fertility of *O. cincta* over its whole life time, but with a maximum of 345 eggs. This implies that a lot of females rarely if ever reproduce. The maximum corresponds very well to that (392) found by JOOSSE, BURGMAN & VELD (1973) over an experimental period of 42 days. The sexual activity decreases with increasing age (decreasing strongly after the 20th instar) as is reported by KORR (1968).

3.2. Embryonic development

HALE (1965) dealed quite extensively with the embryonic development in function of temperature, in several species of springtails. He used the equation $K = D(T - C)$ in which T is the temperature, C the developmental zero, D the time of development expressed in days, and K a thermal constant.

Table 1. The development time (D) and the development rate $\left(\frac{1}{D}\right)$ as a function of the temperature (T)

T	D	1/D
0.0		0.000
10.0	38	0.026
12.5	21	0.048
13.5	16	0.063
14.5	16—14	0.063—0.071
15.0	15	0.067
15.5	12	0.083
20.0	7.5	0.133
21.0	9	0.111
22.5	9	0.111
23.5	6—6	0.167—0.167
24.0	8	0.125
24.5	7	0.143
30.0	5.5	0.183

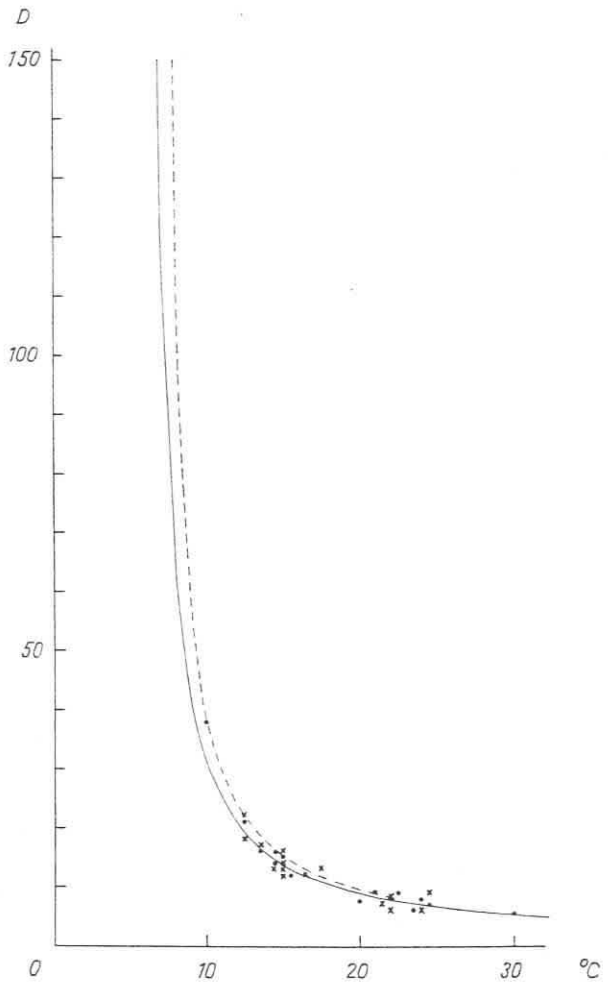

Fig. 5. The embryonic development time D (days) as function of the temperature T (°C) in *O. cincta* (———) and *O. villosa* (------). The dots (*O. cincta*: ● ; *O. villosa*: ×) correspond to the experimental values.

Table 2. The chorion split and the eye pigmentation as a function of the temperature, expressed as percentage of total development time

Temperature °C	Chorion split	Eye pigmentation
10.0	17.11	52.63
12.5	19.05	—
13.5	31.25	62.50
14.5	25.00 – 28.57	62.50 – 78.57
15.0	26.67	53.33
20.0	—	66.67
23.5	16.67 – 16.67	50.00 – 66 – 67
30.0	9.09	36.36

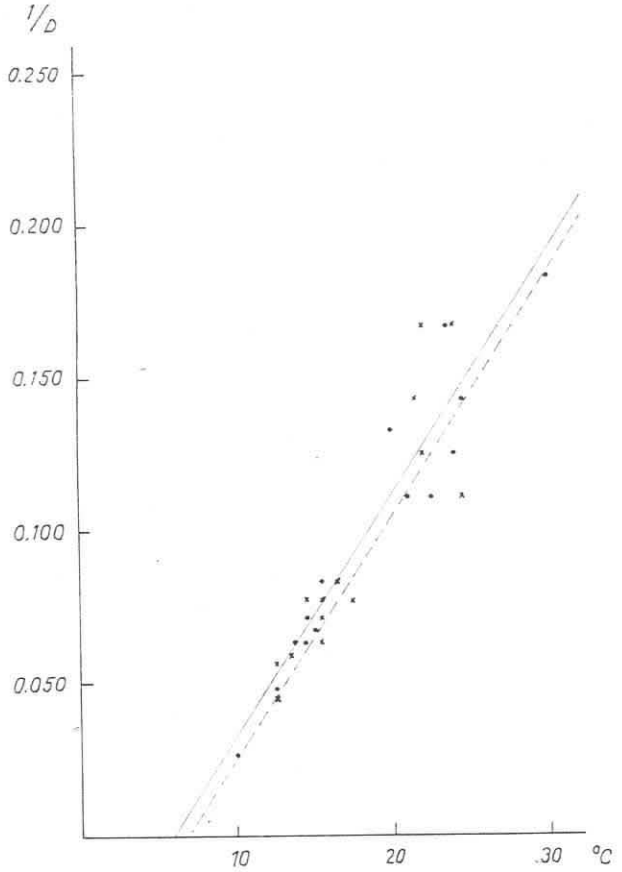

Fig. 6. The development rate $\frac{1}{D}$ as function of the temperature T. The symbols are the same as in Fig. 5.

The development time $\left(D = \frac{K}{T - C}\right)$ is hyperbolic in a temperature time diagram. The relation between temperature and the development rate (1/D, the reciprocal of the egg development time) is linear our experimental data are given and compared with the data of LINDEMANN (1950) in Table 1 and Fig. 5 and 6. By curve fitting of the linear regression $1/D = a + bT$, the coefficients become $a = -0.048$ and $b = 0.008$ (corr. coeff. 0.91).

Since $D = \frac{K}{T - C}$ and $D = \frac{1}{a + bT}$ $\left(\text{from } \frac{1}{D} = a + bT\right)$ we find $\frac{K}{T - C} = \frac{1}{a + bT}$

$= \frac{1}{0.008\,T - 0.048}$ or $\frac{K}{T - C} = \frac{125}{T - 6}$ so that $K = 125$ and the development zero C: 6 °C.

South (1959) and Choudhuri (1961) find respectively in *Entomobrya* and *Onychiu* 4 °C as the developmental zero. Hale (1965) reports values between 0 °C and 3 °C in di ferent species *(Hypogastrura, Onychiurus, Tullbergia, Isotomurus, Lepidocyrtus, Tomocer Dicyrtoma)*.

The moment of the chorion-split and of the eye pigmentation, expressed as percentag of the total development time D at the experimental temperature, are given in table 2. Th average values are respectively 21.12 % (SD 7.15) and 58.80 (SD 12.20).

When replaced at 20 °C, eggs, preincubated at 0 °C for 20 days, resp. 30 days, hatche after 8 days, resp. 7 days, corresponding to a K value of 112, resp. 98. Even after a preinc bation of 138 days (4.6 months) at 0 °C, the embryonic development at 20 °C was norma During the experiments (at 0 °C) water was present in the three stades of aggregation (ic water, vapour). Several times the eggs were enclosed in ice. It is concluded that *O. circ* is able to survive in the egg at temperatures below the developmental zero and that onc above this zero, the development goes on as if no preincubation occurred.

4. Summary

Some aspects of the population dynamics of *Orchesella cincta* are analysed in laboratory popul tions, dealing with: (1) the survivorship and the life expectancy of males and females; (2) the growt curve of both sexes; (3) the reproductive cycle and reproduction; (4) the embryonic development function of temperature.

5. Acknowledgement

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Address of the authors: D. Johan Mertens and D. Jean-Pierre Blancquaert, Laborato voor Oecologie der Dieren, Zoogeografie en Natuurbehoud, Rijksuniversiteit Gent, K.L. L ganckstraat 35, B - 9000 Gent, Belgie.